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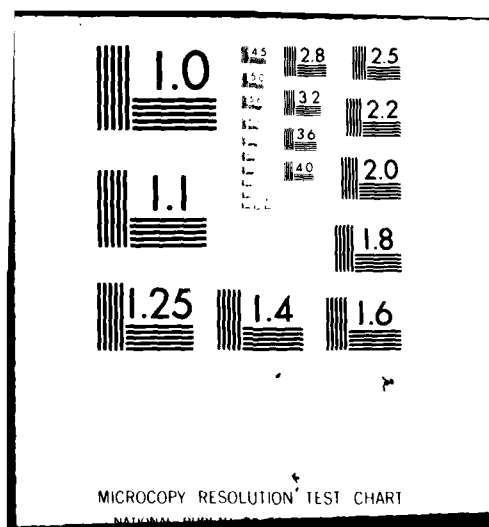
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## FIGURES

1. Drilling camp. From left to right: living quarters, drilling sled, and laboratory-shop sled.
2. Map of the Elson Lagoon vicinity, northern Alaska.
3. Soil temperature profile variations for 10 selected boreholes.
4. Borehole B-2 temperature profile with expanded temperature scale.



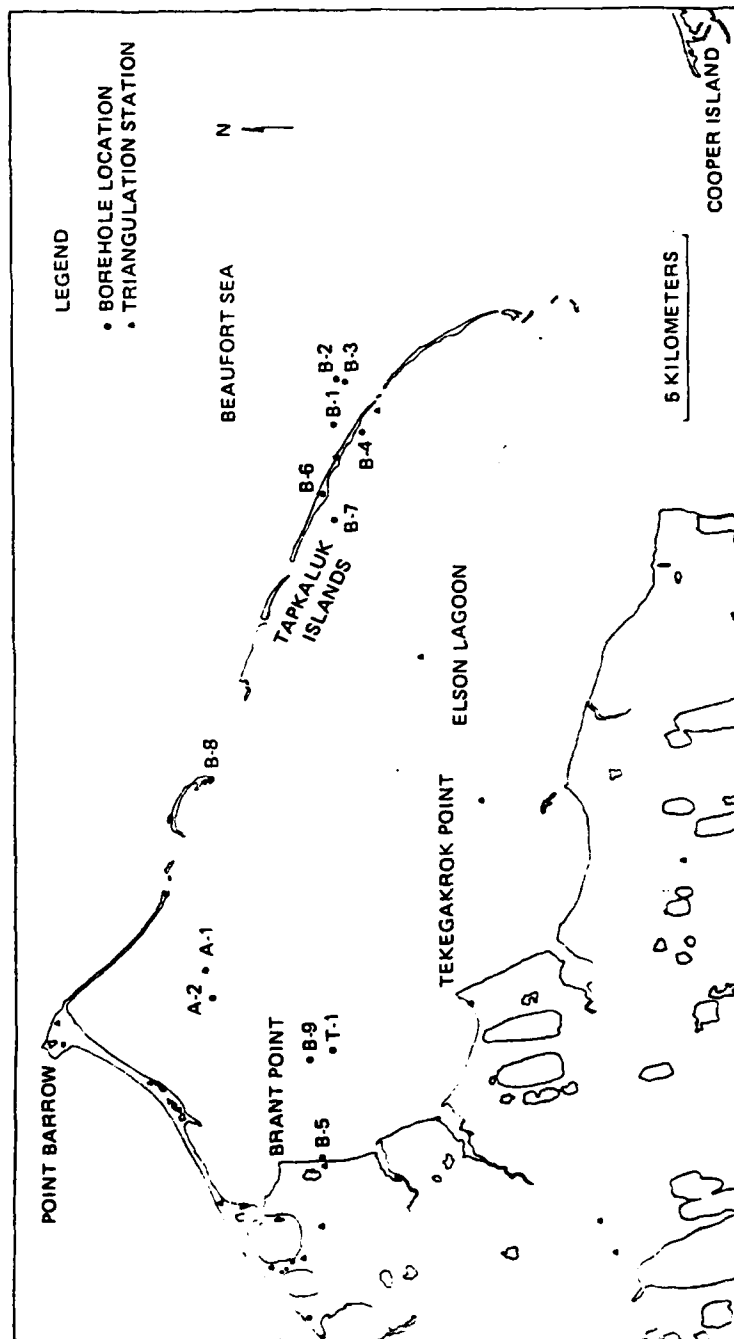


FIGURE 2

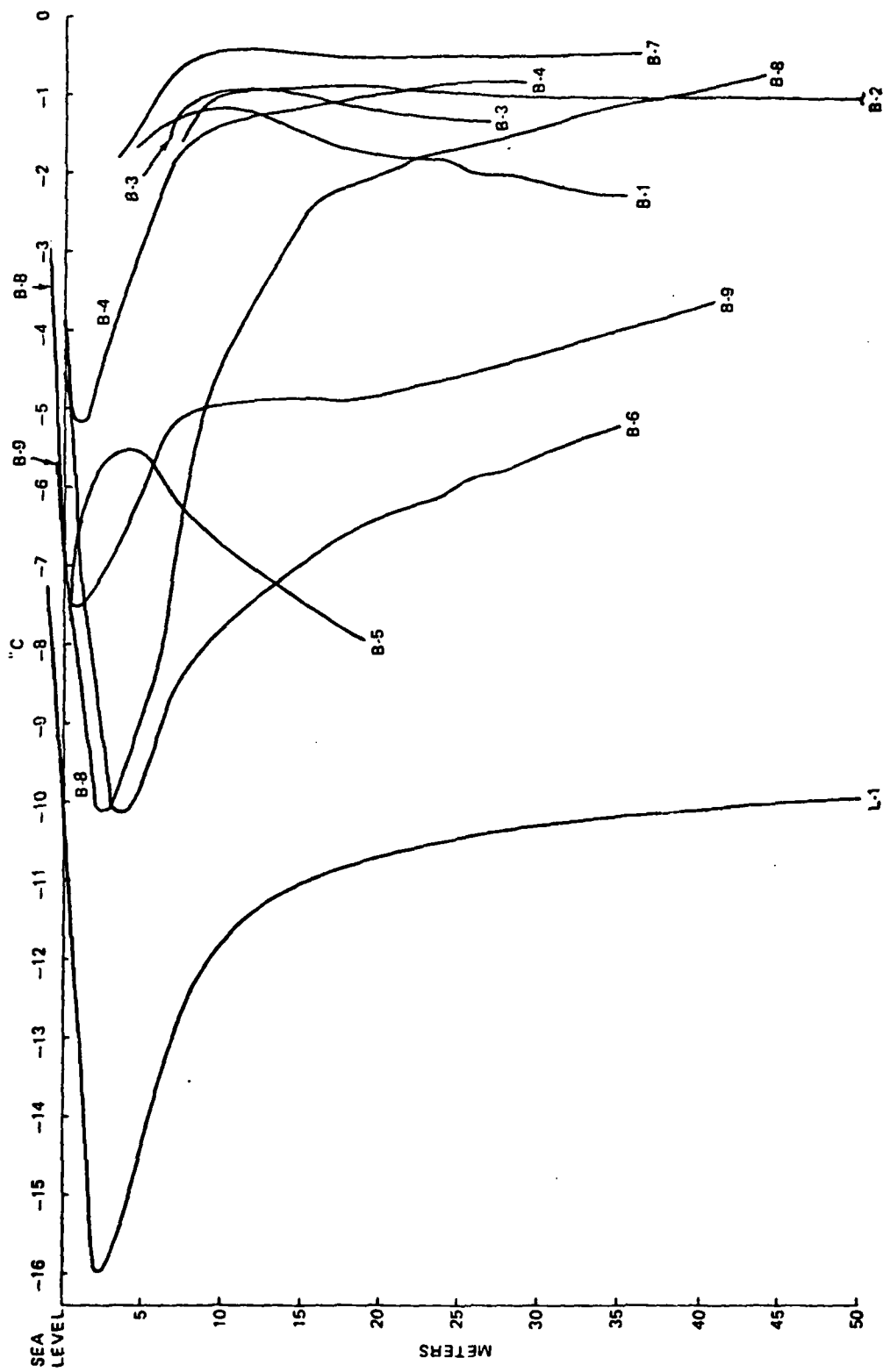


FIGURE 3

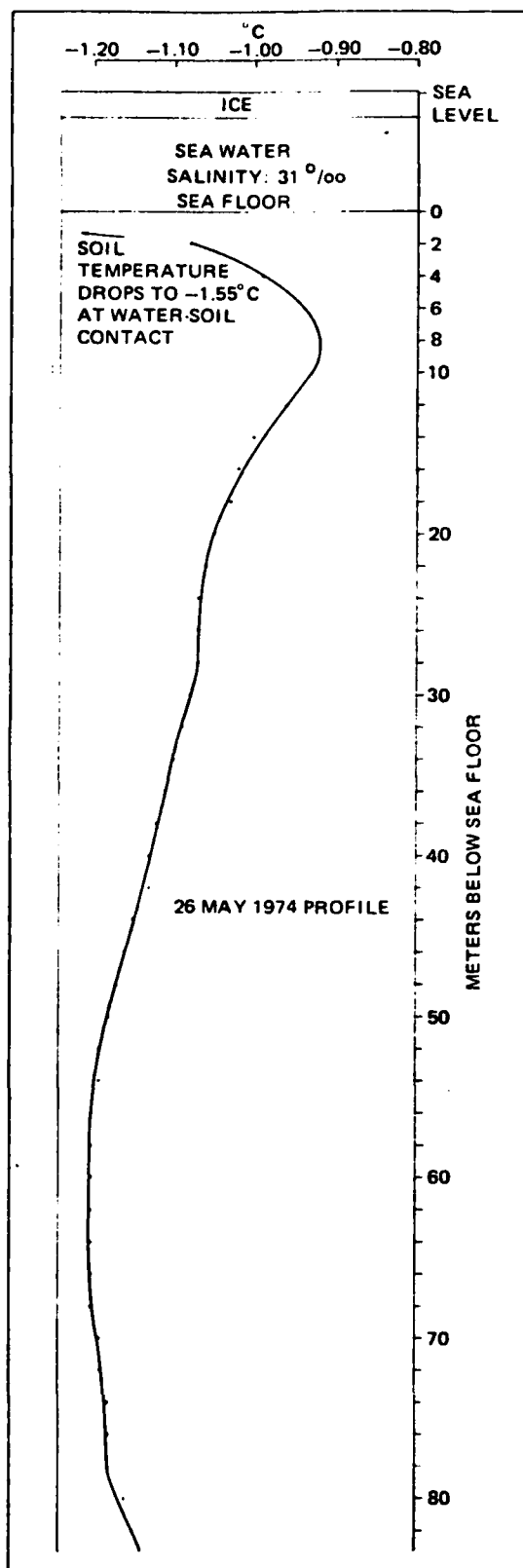


FIGURE 4

## INTRODUCTION

### Definition.

Perennially frozen ground or permafrost is defined as earth material within which the temperature is below  $0^{\circ}\text{C}$  for several years without regard to the state of any moisture that may be present. Permafrost is continuous throughout the Arctic Coastal Plain Province and reaches to depths of up to 600 meters. Investigations have revealed subsea permafrost under the Chukchi and Beaufort Seas.

The subsea permafrost is continuous, but warmer and thinner than the adjacent terrestrial permafrost. The subsea permafrost may be frozen hard with fresh-water ice in the interstices or saturated with brines which have a depressed freezing point.

### Rationale.

Permafrost affects marine activities in the same basic way it affects terrestrial activities. Subsea permafrost

affects sea-floor foundation designs, structural designs, construction and maintenance, the refraction and reflection of sound, and buried transmission systems. The ground-ice content of the thawing permafrost affects soil subsidence and strength. In areas of aggrading bars and shoals, the accelerated development of subsea permafrost can cause the formation of ice lenses, the associated soil heave, and an increase in soil strength.

Information on subsea permafrost is beginning to reach a critical focus as a result of the proposed industrial development. Subsea permafrost information is urgently needed in support of decisions to be made on national defense and security, national energy needs, and environmental considerations. It is very important to remember the indigenous population of northern Alaska. In order to develop their economic independence, the natives will be building breakwaters, winter harbors, piers, etc. in the

near future. Information supplied by the subsea permafrost investigations is required by the decision-makers and design engineers for these projects.

#### Project Development and Requirements.

The subsea permafrost investigations began in the Elson Lagoon area near Point Barrow, Alaska during the year 1971 (Lewellen, 1973, p. 131-136). One of the initial objectives was to develop an inexpensive scientific drilling capability. This was realized in 1973 with the drilling of two shallow holes in Elson Lagoon. The operations during April and May 1974 proved that a drilling capability had been developed which could take permafrost cores from beneath the sea floor.

Data is required on the subsea soil thermal and physical properties. Permafrost temperatures are required from the sea floor to depths of 200 meters. Information and data are required on the mean annual sea bottom temperatures,

geology of the Arctic Coastal Plain Province, and the geomorphic processes operating along the present shoreline.

Prior to the drilling capability data was gathered on near-surface soil temperatures, shoreline history, radio-carbon dates, thaw subsidence, geothermal theory, and instrumentation. With the drilling programs information is being compiled on soil temperatures, and soil physical properties including moisture and ice content, salinity and mobility of interstitial waters, density, grain size, thermal conductivity, specific heat and latent heat.

During past field seasons, approximately 12 holes were augered to 6-meter depths in areas where the ice cover freezes into the sea bottom. Three 15-meter holes were drilled with a small drill which was designed to be transported by light aircraft or snow machine. In 1973, two test holes, 16 meters deep, were drilled with the new rotary equipment (Lewellen, 1974, p. 417-426). Five holes

were drilled and sampled during the April-May, 1974 program. Seven boreholes were drilled in 1975, and a total of 540 meters have been drilled since the project started. The drill can reach depths of 450 meters below the sea floor; however, until this year, only 92 meters of drill rod had been funded.

#### The Physical Setting.

The area under investigation is the Chukchi and Beaufort shelf adjacent to the Arctic Coastal Plain Province, northern Alaska. The shelf extends for a direct distance of 1100 kilometers from Cape Beaufort to Point Barrow to Demarcation Point. The coast is divided into: (1) barrier islands and lagoons; and (2) mainland exposed directly to the sea. Approximately, 60 percent of the distance is islands and lagoons.. The remaining 40 percent has the mainland exposed to the sea.

Drilling programs are scheduled during April and May

when the light and temperature conditions improve, and the sea ice has attained the maximum thickness. Late winter storms can destroy visibility, attain wind velocities of 80 kilometers per hour, and lower temperatures to  $-40^{\circ}$  C. The wind-blown snow cover varies in thickness from nil to about 50 centimeters.

Past oceanographic records were analyzed in an effort to determine the mean annual temperature at the bottom of the sea water column. The approximate mean annual bottom temperature is  $-1.3^{\circ}$  C for the Beaufort Sea and  $-0.7^{\circ}$  C for the Chukchi Sea. In general, the adjacent land areas have a mean annual surface temperature of  $-9.0^{\circ}$  C.

The upper 20 or 30 meters of the local stratigraphy consists of the Gubik Formation of Pleistocene age. The upper part of the formation is the sandy Barrow unit. The basal unit is poorly sorted fine sands, silts, and clays. Gray and black clays with some silts underlie the Gubik

Formation. The Pleistocene-Cretaceous contact occurs consistently at about 30 meters throughout the Elson Lagoon area.

#### CONCEPTS AND SITE SELECTION.

Approximately 20,000 to 40,000 years ago the sea level lowered to a point about 100 meters below the present level. The climate was severe enough to form permafrost in the emergent soils. Next, a transgression occurred from approximately 5,000 to 20,000 years ago. The transgression inundated a permafrost terrain which is analogous to the present Teshekpuk section of the Arctic Coastal Plain. The transgressing sea had water temperature approximately the same as the present water temperatures.

Past permafrost and geomorphic studies conducted on the Teshekpuk section are utilized in the study of the relict conditions under the sea. The geomorphic processes, rates, and changes in the rates are important in the interpretation

of the subsea temperatures. The present terrestrial and marine processes operated during the transgression, but under different time intervals and at different rates.

Relict thermal anomalies caused by streams, oriented lakes, and shifting barrier islands can be identified under the present sea floor. Relict marine features, similar to those of the present, have been identified on the emergent coastal plain and on the sea floor.

Drilling locations are selected on a geomorphic and thermal basis. Seven situations are outlined as follows:

- (1) eroding shorelines, including thermal planation or truncation within lagoons and along shores exposed to the sea;
- (2) flat lagoon floors;
- (3) bars and shoals, including lagoons, both where the ice freezes into the bottom and where ice floats, and barrier islands exposed to the sea;
- (4) barrier islands, including active islands as well as inundated relics which are either terrestrial remanants or

constructed by stillstands; (5) flat floors seaward of the barrier islands; (6) flat floors seaward of mainland shores exposed to the open sea; and (7) deltas.

#### OPERATIONAL TECHNIQUES

##### Sleds.

Two Panitchek sleds, 4 by 7 meters, are used to support and move the drilling camp (Figure 1). Both of these sleds have runners 5.5 meters long and 15 centimeters wide, and are rated at 18 metric tons capacity. The sleds are just two of many which were constructed in 1952 by Fred Panitchek for supporting the exploration of petroleum in Naval Reserve Number 4. Four years ago the sleds were refitted with new wooden enclosures.

One of the sleds carries the water tank, portable mud pit, mud pump, the drill, and casing and rod. The other sled is a combination laboratory and shop carrying a walk-in cold room, toilet, heating stove, generator and supplies.

Living quarters for the 3-man crew are mounted on a Micheler sled.

#### Slip-Joint Casing.

The shorefast ice sheet responds to tidal changes.

Alignment of the drilling equipment is a problem with surface casing placed firmly in the sea floor. Therefore, a slip-joint casing device was developed to compensate for the tidal movement. A piece of steel tubing threaded on on both ends telescopes over the casing. The length of the tubing is a function of the vertical movement range. After placing the tubing over the casing, an annular packer is threaded onto the lower end of the tubing. The tubing is lowered below the top of the casing, and another annular packer is threaded into the casing threads. The tubing is then pulled up past the casing annular packer, fastened firmly to the rotary table on the drill, and a mud discharge tee is finally threaded onto the top of the tubing.

#### Drilling Mud.

Small diameter holes (7.6 centimeters) are drilled in order to reduce thermal disturbance. Sea water is used as a circulating media, and the clay content of the formations builds an adequate mud by the time the bit reaches 20 or 30 meters depth. The drill water salinity is sampled periodically. The circulating water salinity will drop in zones of low salinity pore waters; the circulating water salinity will correspondingly rise in zones of brine.

Mud temperatures are controlled to within a couple of degrees of the actual soil temperatures while drilling the sea floor locations. The mud temperature cannot be controlled easily for the island and mainland locations; ice build-up in these boreholes is a problem.

#### Casing.

Surface casing extends from the sea floor through the water column, and through the sea ice cover. The amount of

casing required below the sea floor or island surfaces varies from about 10 meters to 30 meters. The hole will usually stay open after the clay formation is encountered at 30 meters.

After the total depth has been drilled and sampled, a plastic casing is run in the hole. The plastic casing is standard schedule 40 PVC about 3 centimeters in diameter. The PVC casing is filled with Arctic grade diesel fuel. For temporary observation sites, the steel casing is pulled leaving the plastic casing behind. Since the hole through the ice sheet will freeze back and collapse the plastic pipe or break it off by tidal action, a layer of oil-soaked cotton material is placed around the PVC through the ice section. At permanent installations the steel surface casing is left in place, the plastic run inside, and the steel casing capped.

Transmission section.

### Instrumentation.

Precision calibrated thermistors are used to sense the ice, sea water, and soil temperatures. The thermistors change approximately: (1) 320 ohms in the temperature range of  $-10^{\circ}$  to  $-5^{\circ}$  C; (2) 240 ohms in the range of  $-5^{\circ}$  to  $0^{\circ}$  C; and (3) 170 ohms from  $0^{\circ}$  to  $+5^{\circ}$  C. Earth temperatures determined to  $0.01^{\circ}$  C are required for permafrost studies. Therefore the Wheatstone bridges must be capable of accurately measuring and resolving 1 to 3 ohms.

Two instruments are used to read the thermistors, a calibrated Data Precision digital multimeter (model 2540), and a Leeds and Northrup precision Wheatstone bridge equipped with an electronic null detector. The thermistors are attached to 4 conductor cables (Berk-Tek, BTONX-734-2F-Q) which vary in length from 30 to 300 meters. One of the conductors is used for a common lead, one for measuring the lead wire resistance, and the remaining leads for two

thermistors. Boreholes are logged going into the hole to prevent agitation of the diesel fuel. When the thermistors reach the desired depth, each thermistor and the lead wire resistance are measured independently. Readings are made immediately after drilling and after the borehole drilling disturbance has dissipated which may take a few weeks.

#### SELECTED RESULTS

The earth temperature profiles are functions of the mean annual land surface or sea bottom temperatures. The land surface mean temperature is many degrees lower than the sea bottom. Seasonal temperature variations on land, having a large annual amplitude, affect the upper 15 or 20 meters of the temperature profiles. The very low annual variations occurring on the sea floor affects only the upper few meters of the profile.

Figure 3 illustrates the general temperature profiles for the boreholes. Borehole L-1 is located 100 meters inland

from an eroding shoreline near Kolovik. Site L-1 represents the inland soil temperatures prior to any great influence by the marine environment. The upper 3-meter temperatures reflect the warmer spring temperatures (5 June 1975) after a long cold winter.

Profile B-5 (24 October 1974) is from a hole located only 6 meters from the western Elson Lagoon shoreline. The shoreline is thermally eroding at a rate of 1 to 2 meters per thaw season. The observations illustrate the cooling taking place in the upper few meters. The lower part of the curve reflects the disequilibrium condition created by the lagoon shoreline passing over the area. An extension of the B-5 profile would eventually coincide with the lower end of the L-1 profile.

Profiles B-2 and B-3 illustrate the effect of the open sea beyond the barrier islands. B-1 would be similar to B-2 and B-3 except it has been influenced by the migration

of the adjacent barrier island. B-4 profile is from a borehole located 55 meters from the barrier island shore. The B-4 soils are cooling concurrently with sedimentation as the barrier island migrates westward. Holes B-1, 2, and 4 were observed on 26 May 1974. Hole B-3 was observed on 2 June 1974.

Temperature profile B-7 illustrates a warmer and deeper part of the lagoon prior to influence by the approaching barrier islands. Profile B-7 was observed 20 May 1975. Profile B-8 (7 June 1975) illustrates the rapid cooling conditions occurring concurrently with sedimentation on Deadman's Island. Segregated ice lenses occur in the upper 7 meters of this borehole; they develop as the cold wave penetrates into the soil.

Profile B-6 (7 June 1975) also illustrates cooling conditions associated with the establishment of barrier island conditions. A comparison between B-6 and B-8 reveals

the greater age for the B-6 barrier island.

A large bar extends north of Tekegakrok Point across the lagoon and almost to the north shore. The bar is covered by about 1 meter of water. Profile B-9 (7 June 1975) was observed in the Tekegakrok bar sediments. The shallow waters over the bar decreases the annual temperature variation, and this is reflected in the upper few meters of the profile.

Figure 3 provides a generalized comparison of the soil temperature variations. However, Figure 4 illustrates, on an expanded temperature scale, the great amount of detail present in the data. Seasonal variations occur in the uppermost part of the profile. The lower part of the profile illustrates a disequilibrium condition which was initially disturbed by the last transgression as it passed over the land surface.

Boreholes B-4, 6, and 8 have proved that the barrier

islands are just gravel and sand deposits which are overlying lagoonal sediments. The barrier island deposits are 2.6, 3.0, and 3.7 meters in thickness. Other barrier islands along this coast are mainland remanants.

#### ACKNOWLEDGEMENTS

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